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Assessing Ecosystem Level Carbon Loss and Mitigating Capacity of Rubber (*Hevea brasiliensis*) Plantations in Hilly Regions in India

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Abstract

Ecosystem level carbon loss and the resultant loss of CO_2 mitigating capacity of rubber (*Hevea brasiliensis*) plantations of 23 and 30 years in a hilly urbanized terrain dominated by development and construction activities was investigated. The total carbon loss of the rubber ecosystem due to the destruction of a surface area of 10, 25, and 50 hectares of rubber plantation was derived from published data of destructive tree felling based on the biomass and carbon sequestration potential of one hectare of rubber plantation. The popularly cultivated clone RRII 105 since 1980 occupying 85% of the total rubber area in India was chosen for the study. The data was analyzed using ANOVA and Standard Error (SE) Means for the base data and extrapolated to ecosystem-level calculation. Results revealed a total ecosystem carbon loss of 2142, 5355, 10710 tons for 23 years and 3415, 8538, 17075 tons for 30 years under deforested area of 10, 25, and 50 hectares, respectively. The carbon loss (tons) from tree biomass (tons) removal was 570, 1425, 2850, litter fall was 575, 1438, 2875 and sheet rubber was 432, 1080, 2160 for 23 year plantation. In 30 years plantation, carbon loss from tree biomass was 1480, 3700, 740, litter fall was 750, 1875, 3750, and sheet rubber was 621, 1553, 3105 tons. Total soil carbon stock loss (tons) was 565, 1413 and 2825 for both 23 and 30 years, since the soil carbon stock was calculated similarly with one value for both plantation years. Other studied clones such as RRII 414, RRII 429, and RRII 417 recorded 44-50 percent higher carbon loss compared to RRII 105. The highest carbon loss was recorded in the central part and lowest in the area with severe drought. The study clearly depicts the importance of rubber plantations in mitigating climate change due to massive removal of rubber plantations, an important economically and environmentally sustainable agro ecosystem. The study recommends for putting in place appropriate policies and regulations to restrict the removal of economic tree plantations for ecosystem sustainability.

Keywords

Ecosystem; Carbon loss; Urbanization; Impact; Rubber plantation

Introduction

Terrestrial carbon reservoir in tree ecosystems is important because it is cost effective, natural and environment friendly (Anjali, Khuman and Sokhi, 2020). Population increase and associated developmental activities, such as urbanization and construction, are inevitable. As a result, a huge amount of atmospheric carbon dioxide (CO_2) contributes to the emission of Green House Gases (GHGs). Urbanization and related shift in land use (from a tree-based ecosystem to other uses through tree removal) cause a reduction in the carbon reservoir, resulting to accumulation of CO_2 in the atmosphere (Sallustio *et al*., 2015). This is a leading cause of climate uncertainties, and loss of water resources, functional microbes and biodiversity.

Rubber tree (*Hevea brasiliensis*) is one of the most important and major raw materials for tyre manufacture and various rubber goods in the world. The tree has an economic life span of 25-30 years with massive biomass accumulation (Karthikakuttyamma *et al*., 2004). The total carbon stock for the clone RRII 105 is 1.2 ton/tree (Jacob, 2003a). It acts as a huge store house of carbon, i.e. 142 ton/ha in the form of tree biomass and 23 ton/ha inside the soil (Jacob, 2003a). However, differences do exist clone-wise and age-wise in the biomass and carbon stock capacities (Ambily and Ulaganathan, 2015; Karthikakuttyamma, 1997). The net ecosystem exchange[1] (NEE) of CO_2 of rubber plantation is 1-25 g/m^2/day, which shows that rubber plantations are good for carbon sequestration (Annamalainathan, Satheesh and Jacob, 2011). The advanced technology used for rubber processing reduces the CO_2 emission and enhances the sustainability of the rubber ecosystem (Rajagopal and Sebastian, 2011). The varieties developed and established have high carbon storage potential (Ambily *et al*., 2012). Estimating carbon loss from removal of large areas of rubber plantations is very important, but, unfortunately, no data is available in this context. However, the present study investigates the loss of carbon stock from 10, 25 and 50 hectares area of rubber plantations measured in the form of tree biomass, annual litter fall, soil storage and sheet dry rubber storage at the ecosystem level. Such an estimate will help in the formulation of policy measures and prepare guidelines for environmental sustainability of the rubber ecosystem.

Materials and Methods

Study Area

The Rubber Research Institute of India (RRII) is located at 09^{0}32’ N of the equator and 76^{0}36’ E of the Greenwich Meridian. The study was carried out within the experimental fields of the Central Experimental Station - CES (09^{0}22’ N; 76^{0}50’ E) at Chethackal in Pathanamthitta district, Kerala, India. The biomass accumulated, carbon storage and carbon sink loss of RRII 400 series and RRII 105 of 20 years of age is found in three diverse environments in the traditional rubber cultivated areas in Kerala *viz*, Kanyakumari of south region (08^{0}26’ N; 77^{0}36’ E), Chethackal, Kottayam of central region (09^{0}22’ N; 76^{0}50’ E) and Padiyoor - drought affected north region (11^{0}58’ N; 75^{0}35’ E). The area is characterized by a humid equatorial climatic type with high rainfall totals ranged from 1800 to 3400 mm annually. The maximum average annual

[1] https://svs.gsfc.nasa.gov/5047/

temperature is 25º C, while the average minimum is 24.7º C ranged from 20º C to 34º C suggesting a relatively high constant temperature with a low range. The vegetation of the area is characterized by the equatorial rainforest and plantation and annual crops including coconut, rubber, cashew, arecanut, coffee, cardamom, pepper, tapioca, paddy, banana and other crops. The geological formations including the Charnokite, laterite and granite-gneiss land forms. The major soil is lateritic in nature under the Ultisols and Inceptisols and majority rubber plantations were lies in midland and high lands.

Data Collection

Data for the study was collected from both primary and secondary sources. Primary data sets were collected from the field through the selection of rubber plantations of 23 and 30 years from the experimental fields of the RRII for carbon loss assessment. Carbon loss was assessed by uprooting trees using standard procedures of destructive biomass estimation for one hectare plantation (Ambily *et al*. 2012; Ambily and Ulaganathan, 2015). This data was used for the projection of carbon loss assessment under a surface area of 10, 25 and 50 hectare for possible degradation of rubber plantations due to urbanization and construction. Secondary data was collected from annual reports of the RRII, journal articles and the Google search engine.

Sampling Scheme

In this study, a stratified random sampling design was adopted with stratification based on age and clone evaluation. The earlier study adopted a Randomized Block Design (RBD) with equal replications of 5 plots (10 m x 10 m) within two treatment levels: two crop treatment levels (plantation crop age series) based on the earlier study and three projected surface area level (surface area of 10, 25 and 50-hectares). These were evaluated to estimate the quantity of carbon loss. The clones *viz*. RRII 429, RRII 414, RRII 417, RRII 430 & RRII 105 were selected for the study and these were the modern clones released for farmer's adoption. The carbon sink loss for one-hectare plantation was estimated by the destructive tree uprooting method and extrapolated to obtain 10, 25, and 50-hectare area accounts of carbon loss for the clone RRII 105 with soil stock, litter fall input, carbon stock in rubber sheet for the total account of ecosystem-level calculations.

Estimation of Carbon Loss

The earlier study (Ambily, Ulaganathan and Sathisha, 2022) of carbon sink loss per hectare rubber plantation, the carbon sink loss for the various clones was as follows: RRII 429 (114), RRII 414 (106), RRII 417 (102), RRII 430 (60), RRII 105 (57) and RRII 422 (54) ton per hectare. This was taken as the standard to calculate the ecosystem level estimation for the surface area 10, 25 and 50 hectare. The carbon sink loss of RRII 105, RRII 203, and GT 1 at 30 years of age was 148, 138 and 258 tons per hectare. The carbon sink loss of 56.5 for one hectare of soil was estimated as common for both years since the data of carbon stock in soil were taken from the uprooted age only, not a series of data. The carbon loss through annual litter fall recorded was 2-3 ton per ha carbon synthesized from the data published for annual litter fall for the clone RRII 105 estimated at 5-6 ton per ha (Philip *et al.*, 2003). The carbon locked/ carbon loss by rubber sheet (2.7 t/ha/year) in one hectare plantation was assessed as the loss of long term locked up

carbon in the form of tyre and other rubber goods carbon. The above data were used to project the possible carbon sink loss for an area of 10, 25 and 50 rubber plantation through urbanization and construction.

The carbon sink loss of 10, 25 and 50 hectare rubber plantation from urbanization and construction for the clones of RRII 400 series and RRII 105 at 20 years in three diverse environments in the traditional rubber cultivated areas in India *viz*. Kanyakumari (South region), Chethackal, Kottayam (Central region) and Padiyoor (Drought affected North region) were also estimated separately and compared with the published studies on biomass estimation and carbon loss in one hectare rubber plantation (Ambily, Ulaganathan and Sathisha, 2022).

Statistical Analysis

The data was analysed using ANOVA and Standard Error (SE) Means for the base data and extrapolated to ecosystem level calculation.

Results and Discussion

Results revealed that the carbon content of plant parts were different within the rubber tree (James, 2003a) and is given in figure 1. Highest carbon content was found in sheet rubber (85.38 per cent) followed by seed endosperm (63.48 per cent). Around 38 per cent of carbon was found in timber and coarse root whereas the leaf lamina, petiole, small twigs (fuel wood), fine roots and fruit wall recorded carbon content within the range of 42-47 per cent. Major removal is by timber with trunk and major branches. The small twigs and fuel wood is also removed from plantation for wood purpose. But the leaf, petiole and below ground root portions are usually allowed to decay on the field. Regarding carbon loss, these components are also important since the carbon release to the soil from leaf and root take much time. While the carbon content of seed endosperm is high, the quantity is less when compared to above-ground biomass allowed to decay in the field. With these the carbon content of rubber tree was estimated at 42 per cent of the dry biomass. Based on this, the carbon stock per tree (kg per tree) and carbon sequestration capacity (ton per ha) were estimated. The data was synthesized for the estimation of carbon loss from removal of 10, 25 and 50 hectare rubber plantation.

The carbon loss of RRII 400 series clones with RRII 105 at 23 years age for 10, 25 and 50 hectare is shown on table 1. The carbon loss varied among the different clones. The highest loss recorded was within RRII 429, RRII 414 and RRII 417 compared to RRII 430, RRII 105 and RRII 422. The Carbon losses in tons for 10, 25 and 50 hectares area of clones were RRII 429 (1140, 2850, 5700), RRII 417 (1020, 2550, 3100), RRII 414 (1060, 2650, 5300), RRII 430 (600, 1500, 3000), RRII 105 (570, 1425, 2850) and RRII 422 (540, 1350, 2700) tons, respectively. For 10 hectares area highest carbon loss was recorded for RRII 429 (1160 tons) and lowest in RRII 422 (540 tons). Likewise for 25 hectares area, highest loss was in RRII 429 (2850 tons) and lowest in RRII 422 (2700 tons), and for 50 hectares area, the highest loss was in RRII 429 (5700 tons) and lowest in RRII 422 (2700 tons).

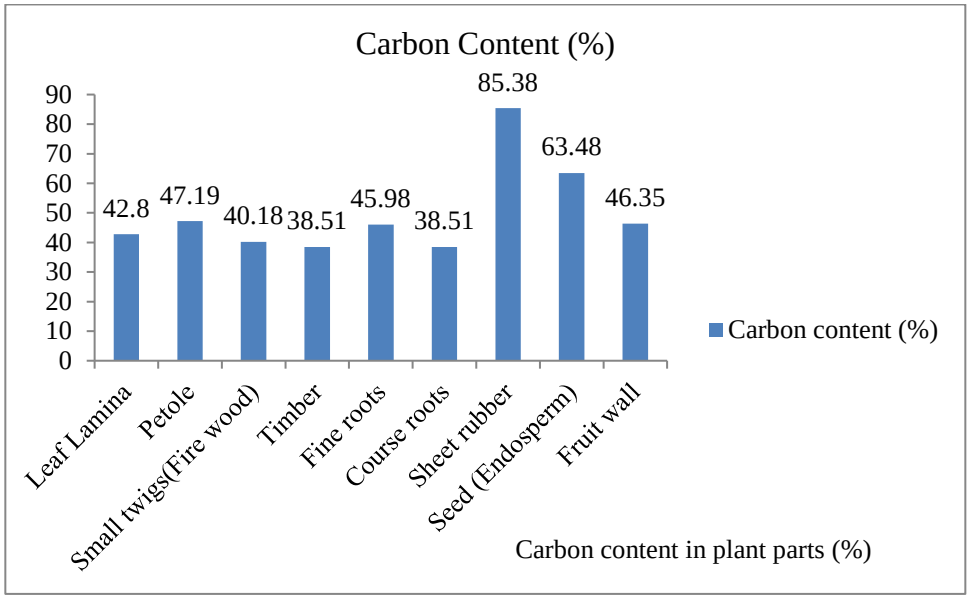

Figure 1: Carbon content in sink sources of rubber plantation [Adopted from Jacob (2003a)]

Table1: Carbon loss by tree removal of RRII 400 series and RRII 105 clones (23 years age) at RRII Farm in the central region of Kerala

C- loss by tree biomass removal (ton)				
Clones	*Area (Hectare)*			
	*1**	*10*	*25*	*50*
RRII 414	106*	1060	2650	5300
RRII 430	60*	600	1500	3000
RRII 429	114*	1140	2850	5700
RRII 417	102*	1020	2550	5100
RRII 422	54*	540	1350	2700
RRII 105	57*	570	1425	2850
CD	5.06*	50.6*	126.5*	253.3*

Adapted from Ambily *et al.* (2012)

The carbon loss of clones in diverse environments *viz*. Padiyoor (PD), CES, Chethackal (CES) in Kerala and Kanyakumari (KK) district in Tamil Nadu state of India for the same clones are presented on table 2. The locations were *viz*. Regional Research Station (RRS) Padiyoor, Kannur district, the drought affected area, Central Experiment Station (CES), Chethackal, Ranni, Pathanamthitta district, the south-central area in Kerala and *Hevea* Breeding Sub-Station (HBSS), Thadikarankonam, Kanyakumari, Tamil Nadu with an extremely different agro-climate and weather events. Even though locations were diverse, the management practices in the rubber plantations were similar. Due to variations in soil conditions, the growth of trees related to clones/weather is different so also is the carbon loss for different clones in the three locations since carbon stock is a direct function of biomass accumulation. The carbon loss in the drought stress north region was in the range of 411-509, 1205-1273 and 2055-2545 for 10, 25 and 50 hectare, respectively, with lowest within RRII 105 and highest in RRII 414. Similarly in the

central region, the carbon loss recorded was within the range of 579-1029, 1448-2573 and 2895-5145 with the lowest in the clone RRII 105 and highest in RRII 429. But in the south region, the carbon loss was in the range of 471-879, 1178-2198 and 2355-4395 tons with the lowest in RRII 430 and highest in RRII 429. Central region showed higher carbon loss as compared to the north and south and the lowest loss in the north. The carbon loss of clones in the two central regions of Chethackal, the south-east region and Kottayam, south-central region both with prevailing weather conditions with an annual rainfall ranged of 3500-4000 mm and mean maximum and minimum air temperatures are 31-32^{o} C and 22-23^{o} C, respectively, were almost similar. The carbon loss was in equal pattern with highest in RRII 414, RRII 429 and RRII 417 and the lowest in RRII 430, RRII 422 and RRII 105. In Padiyoor, the drought affected traditional area in northern region of Kerala, a prolonged dry spell of about four to five months duration from the month of December to May annually is prevailing a constraint for rubber growth. It was reported that in this region because of moisture stress and the presence of dry spells, the growth and yield of rubber tree is affected if total rainfall of 3500 mm is available (Vijayakumar, Chandrashekar and Philip, 2000). The mean maximum and minimum temperature are 33 and 23^{o}C, respectively. The Kanyakumari region and Padiyoor region are entirely different climatically. In Kanyakumari region, evenly distributed rainfall is of 2000 mm annually, and it never exceeds more than 350 mm in any of the months. The south west and north east monsoons are equal and there were no marked temperature variations also.

Table 2: Carbon loss by tree removal of RRII 400 series clones and RRII 105 clones (20 years age) in diverse environments in Kerala

Carbon loss by tree biomass removal (ton)												
Clone	*Area (Hectare)*											
	*1**			*10*			*25*			*50*		
	*PD**	*CES**	*KK**	*PD*	*CES*	*KK*	*PD*	*CES*	*KK*	*PD*	*CES*	*KK*
RRII 414	50.9 ±2.5	92.3* ±7.1	62.9 ±4.26	509 ±25	923 ±71	629 ±43	1273 ±63	2308 ±178	1573 ±107	2545 ±125	4615 ±355	3145 ±213
RRII 430	42.7 ±0.7	69.5* ±4.8	47.1 ±2.1	427 ±7	695 ±48	471 ±21	1068 ±18	1738 ±120	1178 ±53	2135 ±35	3475 ±240	2355 ±105
RRII 429	42.8 ±2.3	102.9* ±3.9	87.9 ±6.1	428 ±23	1029 ±39	879 ±61	1070 ±58	2573 ±98	2198 ±153	2140 ±115	5145 ±195	4395 ±305
RRII 417	48.2 ±3.2	90.5* ±5.92	65.9 ±5.6	482 ±32	905 ±60	659 ±56	1205 ±81	2263 ±148	1648 ±280	2410 ±160	4525 ±296	3295 ±280
RRII 422	41.4 ±3.2	75.8* ±3.1	59.8 ±6.1	414 ±32	758 ±30	598 ±61	1035 ±80	1895 ±75	1495 ±149	2070 ±160	3790 ±149	2990 ±298
RRII 105	41.1 ±2.2	57.9* 3.1±	58.7 ±4.6	411 ±22	579 ±31	587 ±46	1028 ±55	1448 ±77	1468 ±113	2055 ±110	2895 ±153	2935 ±226

*Adopted from Ambily *et al*. (2022); PD = Padiyoor (North); *CES = Chethackal (Central); *KK = Kanyakumari (South); ±Mean standard error (SE) values

The carbon loss of RRII 105, RRII 203 and GT 1 at the age of 30 years at CES Chethackal, in the south-east central region of Kerala is shown in table 3. The carbon loss for 10, 25, 50 hectares was 1480, 3700, 7400 tons, respectively for clone RRII 105. A loss of 1380, 3450 and 6900 tons was observed in clone RRII 203; and 2580, 6450, 12900 tons in case of clone GT1. The variation observed in carbon loss among clones

under similar soil and climatic conditions can be attributed on growth variation due to clonal character.

Table 3: Carbon loss by tree removal of RRII 203, GT1 and RRII 105 at 30 years age at CES Chethackal, south-east central region of Kerala

Carbon loss by tree removal (ton)				
Clone	*Area (Hectare)*			
	1*	10	25	50
RRII 105	148*	1480	3700	7400
RRII 203	138*	1380	3450	6900
GT 1	258*	2580	6450	12900
Mean	188*	1880	4700	9400
SE	31.8*	318	795	1590

*Adopted from Ambily and Ulaganathan (2015); ±SE = standard error values

The carbon losses from soil, litter fall and sheet rubber for 10, 25 and 50 hectares area can be seen in figure 2. The soil carbon loss for one hectare area reported in an earlier study (Ambily, Ulaganathan and Sathisha, 2022) is 56.5 ton. The estimates for 10, 25 and 50 area are 565, 1413 and 2825 tons, respectively. From the litter fall component, the carbon loss for one hectare is 57.5 tons and 75 tons (Ambily *et al*., 2022) for 23 and 30 years. The 10, 25 and 50 hectares area recorded a carbon loss (tons) of 575, 1438 and 2875 for 23 years and 750, 1875 and 3750 for 30 years. In the case of sheet rubber, the reported values (Ambily, Ulaganatahan and Sathisha, 2022) of carbon loss for one hectare area is 43.2 and 62.1 tons for 23 and 30 years, respectively. Accordingly the 10, 25 and 50 hectare quantity reaches 432, 1080 and 2160 tons for 23 years. The 30 years quantity is 621, 1553 and 3105 tons.

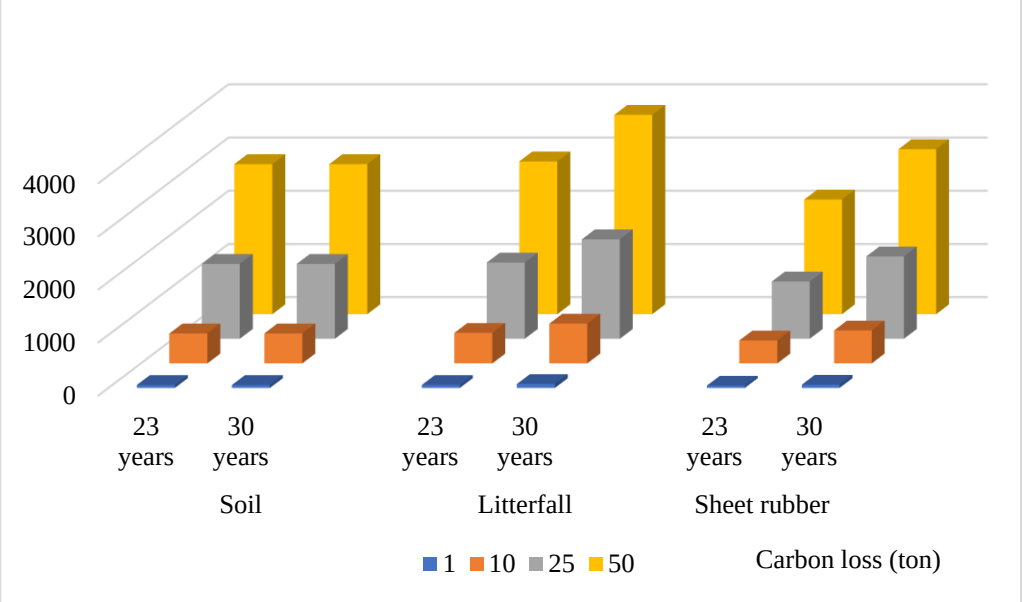

Figure 2: The carbon loss from soil, litter fall and sheet rubber for 10, 25 and 50 hectare area for the clone RRII 105

Total ecosystem carbon loss for 23 and 30 years age plantations for the components of tree biomass, annual litter fall, and soil carbon and sheet rubber for 10, 25, and 50 hectare area for the clone RRII 105 computed is given in table 4. For 23 years, the total carbon loss for 10, 25 and 50 hectares were 2142, 5355 and 10710 tons, respectively. The carbon loss for 30 years was observed to be 3415, 8538 and 17075 tons. Large area removal resulted in very huge loss of carbon from the ecosystem apart from other ecological disturbances for ecosystem-level functions, which are severely reducing the carbon mitigating capacity and causing a higher contribution of GHG's, resulting in global warming and climate change. This necessitates the need to adopt appropriate policy measures and nature-friendly actions as an immediate requisite for sustainability.

Table 4: Total ecosystem carbon loss for 23 and 30 years age plantation from the components of tree biomass, annual litter fall, soil carbon and sheet rubber for 10, 25, and 50 hectare area for the clone RRII 105

Carbon sink sources	*Carbon loss for 23 years (ton)*				*Carbon loss for 30 years (ton)*			
	Area (Hectare)				*Area (Hectare)*			
	1	*10*	*25*	*50*	*1*	*10*	*25*	*50*
Tree biomass	57.0*	570	1425	2850	148*	1480	3700	7400
Soil	56.5*	565	1413	2825	56.5*	565	1413	2825
Litter fall	57.5*	575	1438	2875	75.0*	750	1875	3750
Sheet rubber	43.2*	432	1080	2160	62.1*	621	1553	3105
Total	214.2*	2142	5355	10710	341.5*	3415	8538	17075

*Ambily *et al*. (2022)

It was reported that development and population growth result in the loss of carbon reservoirs. The way forward and suggested option is to strictly form made-up forests rich with vegetation and trees even as plantation with enhanced carbon sequestration potential (Anjali *et al*., 2020). The multi species vegetation can improve biodiversity, soil elements and atmospheric clearances. It will be beneficial to eliminate CO_2 from the atmosphere, thereby, avoiding global warming. Also the increased carbon emission rate due to mobilization of population and automobiles in urban area is also an issue. The plantation of about 2.5 billion density of trees in the midst of the Chinese city can mitigate 1261.4 tons of atmospheric pollution. Besides the enhanced deposit of carbon dioxide to the atmosphere, the storage of carbon in the soils of urban areas is little since there are no tree plantations. A very high degree of carbon loss is resulted by removal of tree ecosystems was reported (Sallustio *et al*., 2015). By maintaining a green vegetation with rich biodiversity plants *per se* showed fast and higher carbon sequestration capacity (Strohbach, Arnold and Haase, 2012). Maintaining a greenery plan for a period of 50 years can sequestered 37.3 and 44.1 mg C per ha carbon in Germany (Strohbach and Haase, 2012). Russell and Kumar (2019) reported that tree plantations with higher content of lignin and agricultural crops with enhanced carbon sequester capacity is one of the most efficient management strategy to mitigate ill effects of urban formation. Because rubber trees possess fairly good amounts of lignin and their ecologically sustained nature (Jacob, 2003b) can be selected as urban trees.

A study by Kaul, Mohren and Dadhwal (2010) showed that the forests in India could sequestrate 101 to 156 mg C per ha in biomass and act as having higher CO_2 mitigating capacity. Alongside this, the forest soils can sequestrate 183 mg C per ha with 20-25 Gt at 0-1 m depth. A similar study (Buchanan *et al*., 2021) of carbon estimates was reported in which the loss of carbon was considered as similar to tree cover loss since these two aspects directly related. Kothandaraman *et al.* (2020) reported that the ecosystem-level carbon stock in tropical forests in India was 336.8 mg C per ha in both biomass and soil. The total carbon stock for the clone RRII 105 in rubber plantation ecosystem comes to 214.5 and 341.5 ton per hectare for 23 and 30 years period. The total carbon stock estimate for 10, 25 and 50 hectare rubber plantation estimated was 2142, 5355 and 10710 tons for 23 years. The corresponding estimates for 30 years were; 3415, 8538 and 17075 tons. The rubber ecosystem was found to be a sound carbon reservoir with an eco-friendly nature and economically profitable. Its removal cannot be compensated and hence very stringent measures should be adopted in an era when urbanization as well as construction activities are intense and destroying the rubber ecosystem. The study is an evident of the huge loss of carbon and CO_2 mitigating capacity by removed rubber plantations and the importance of the steps to be taken as policy decisions to evolve remedial measures in the case of inevitable development activities and urbanization, especially, the environment-friendly hill like tree plantations with fairly good livelihood.

Conclusion

The present study concludes that there is huge loss of carbon and CO_2 mitigating capacity following removal of rubber trees for urbanization and associated construction activities. This has resulted in the damage of the rich carbon reservoir and environmentally sustainable rubber ecosystem. The total carbon loss of the important popular clone RRII 105 for 10, 25 and 50 hectares area for 23 years and 30 years were: 2142, 5355 and 10710 tons for 23 years and the corresponding estimates for 30 years were 3415, 8538 and 17075 tons. The newly established clones RRII 414, RRII 429 and RRII 417 had still higher (44-50 per cent) carbon losses. Due to the growth variation in extreme climatic conditions, the clones recorded differences in carbon stock and, thereby, carbon sink loss. Region-wise variations were observed in carbon loss. The central region of Kerala recorded higher losses. Loss of carbon was lower in north region than South region. This study clearly depicts that the removal of rubber plantation and its carbon storage potential is irrecoverable and cannot be compensated there is, therefore, a need to put in place urgent and robust measures targeted at reducing carbon loss. The study recommends that it is imperative to solve the unscientific land acquisition through policy interventions during the planning of urban areas and construction works. It is beneficial to enhance the ecosystem formation with mixed green vegetation along with rich biodiversity plants *per se* having faster carbon sequestration capacity. The education of the importance of the vegetation and ecosystem conservation in government decisions should be of prime importance.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*
Conceived and designed the research or analysis	Yes	Yes
Collected the data	Yes	No
Contributed to data analysis & interpretation	Yes	Yes
Wrote the article/paper	Yes	No
Critical revision of the article/paper	Yes	Yes
Editing of the article/paper	Yes	Yes
Supervision	No	Yes
Project Administration	No	Yes
Funding Acquisition	No	No
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